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Chemical-physical and ecological characterisation in the environmental project of a polluted coastal area: the Bagnoli case study

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Abstract

*The Bagnoli Bay (southern Tyrrhenian Sea, Naples, Italy) has been impacted for about one century by heavy anthropogenic pollution due to an important steel plant. A multidisciplinary environmental research, aimed at the reclamation of the marine contaminated area, was planned in order to evaluate, through quantitative data, the chemical-physical and ecological characteristics of marine sediments; the latter ones are strictly related to the composition and structure of benthic foraminiferal assemblages. A comprehensive statistical approach, considering all data, was attempted in order to single out the influence of pollutants on the single species distribution. The results show strong heavy metal pollution (Fe, Mn, Pb and Zn) in the vicinity of the industrial plant. Many foraminiferal species (*Haynesina germanica*, *Miliolinella subrotunda*, *Quinqueloculina parvula*), have a good tolerance to some trace metals while, *Bulimina sublimbata*, *Elphidium macellum* and *Miliolinella dilatata* show a good tolerance to PAHs pollution.*

Keywords: Steel Plant, Foraminifers, Heavy Metals Pollution, Organic Matter, Grain Size, Statistical Analysis.

Introduction

The activity of an important steel plant, which lasted almost one century, had a heavy impact on the Bagnoli coastal marine environment (Gulf of Naples, Italy). Industrial production started in 1905 and ceased in 1990.

Recently, the Ministry of the Environment proposed a law, which provides for the restoration of the coastal marine areas with heavy anthropogenic pollution. To this end, a complete environmental research has to be carried out. Bagnoli was the first site that was

studied in the ambit of this law and its characterisation project may be considered as a model for successive studies on other polluted areas. In order to plan the reclamation, an interdisciplinary approach is necessary for evaluating quantitatively the chemical-physical and ecological characteristics of marine sediments. The latter one was determined by the study of benthic foraminiferal assemblages.

In fact, in the last few years, the utility of benthic foraminifers in pollution monitoring has been confirmed by many researches both in natural environments and laboratory

cultures (YANKO *et al.*, 1994; YANKO *et al.*, 1998; ALVE & OLSGARD, 1999; STOUFF *et al.*, 1999; COCCIONI, 2000; SAMIR, 2000; DEBENAY *et al.*, 2001; SAMIR & EL-DIN, 2001). They found that heavy chemical pollution determines environmental stress that modifies the composition and structure of benthic assemblages and may be responsible for test abnormalities in some species that may be regarded as bio-markers.

The research on the Bagnoli area was conducted in distinct phases and is still in progress. The first phase concerned a preliminary evaluation of type, degree and extent of pollution, which was achieved by means of physical (grain-size), chemical (heavy metals, PAHs, PCBs, Organic Matter) and ecological (benthic foraminiferal assemblages) analyses (BERGAMIN *et al.*, in press).

Results show strong heavy metal pollution near the steel plant. Chemical pollution has a severe effect on the sea-bottom's ecological health; the increasing heavy metal concentration reduces the benthic productivity, which may result in the total absence of foraminifers. Moreover, a significant percentage of *Miliolinella subrotunda* specimens show an irregular test. The abundance of such specimens seems related to the Cu concentrations (BERGAMIN *et al.*, in press).

The second phase was aimed at checking and developing the results of the first phase. Then, some significant areas identified by preliminary results, were studied in more detail and, as regards foraminifers, new data about bio-indicators were researched. Grain-size, Heavy Metals (As, Cd, Cr, Cu, Hg, Ni, Pb and Zn), Polychlorobiphenyls (PCBs), Polycyclic Aromatic Hydrocarbons (PAHs) and Organic Matter were determined; moreover, the ecological study on benthic foraminiferal assemblages was included in the project.

In this paper, the preliminary results on chemical-physical analyses (grain-size, heavy metals, PAHs, Organic Matter) and the ecological study (benthic foraminifers) are reported. Analytical data have been treated

with statistical methods in order to evaluate how the distributional patterns of the single foraminiferal species are influenced by the chemical-physical characteristics of the bottom environment. This approach may be useful to single out those species that may be considered bio-markers as they are particularly tolerant or intolerant of single pollutants.

The study area

The Bagnoli industrial site is located in the eastern area of the Pozzuoli Gulf (Gulf of Naples, Tyrrhenian Sea, Italy), between Nisida Island and Bagnoli town, along the Coroglio-Bagnoli beach (Figs. 1 and 2). The gulf coastline has been strongly modified by construction works. Two long piers were built in 1920 in front of the steel plant in order to permit the access to large tonnage boats to increase industrial productivity. The artificial link between Nisida Island and the mainland was built in 1935, so modifying the local water circulation pattern and sediment distribution. In 1962-1964 part of the sea stretch enclosed between the two piers was filled in, utilising polluted ground taken from the industrial area, in order to permit widening and the development of industrial activity. Consequently, the natural coastline was altered and the new spaces so obtained were utilised for the construction of new industrial buildings and the storage of fossil coal. Finally, some littoral stretches (Coroglio beach and Bagnoli beach) were artificially enlarged with alloctonous sand for touristic purposes.

As regards the geological setting, the Pozzuoli Gulf belongs to the Campi Flegrei volcano-tectonic system. It is an area of recent collapse, which occurred about 12-10 kyr BP; it is characterised by four morpho-structural units: the coastal shelf, a central collapse area, the volcanic banks and the external shelf (DE PIPPO *et al.*, 1984). The presence of many subaerial and submersed hydrothermal sources, linked to volcanic activity, may condition the natural chemistry of coastal marine waters and change the parameters for the evaluation of

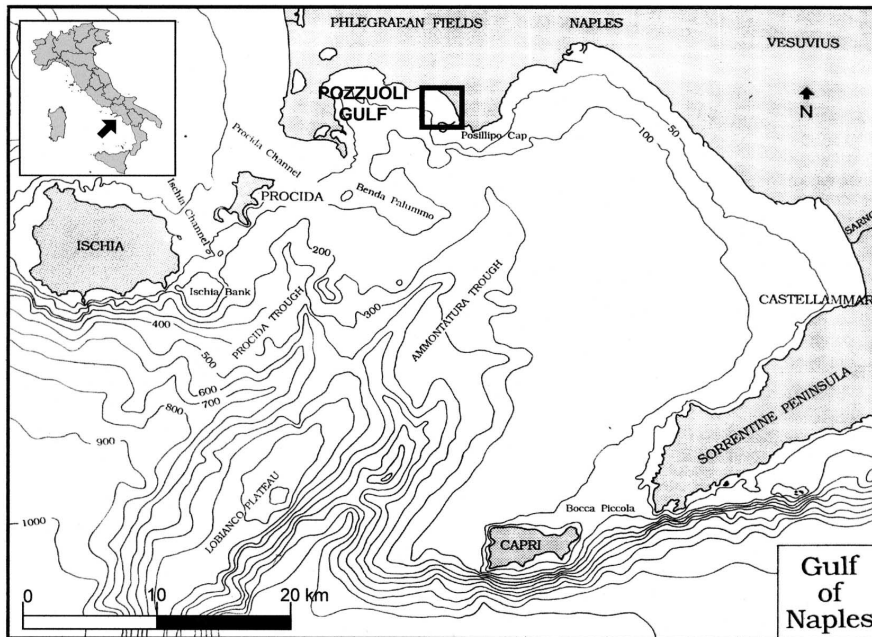


Fig. 1: Location of the Pozzuoli Gulf in the Gulf of Naples. The black square indicates the study area. (after SGARRELLA & MONCHARMONT-ZEI, 1993, modified)

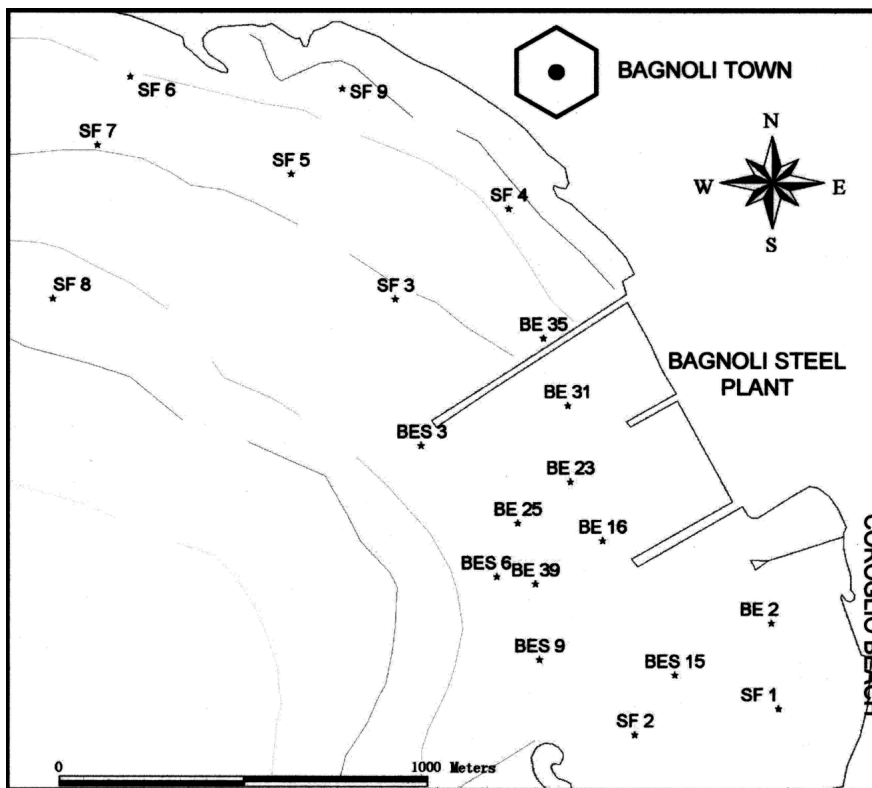


Fig. 2: The Bagnoli marine area. Location map of sampling sites.

change the parameters for the evaluation of anthropogenic pollution.

Sediment distribution in the Pozzuoli Gulf is strictly correlated to climatic and tectonic events. On the littoral shelf, sediments range from coarse sands to sandy-silt. They partly represent relict deposits of ancient beach. The coarse fraction is constituted of bioclastic and pumice-stone elements. In the central basin, sediments consist of silt and silty-clay (DE PIPPO *et al.*, 1988). In the coastal area (0-30 m water depth) of the Pozzuoli Gulf, the sediment samples are normally composed of sand and only in the hydrodynamically-protected areas, like Nisida bay, the pelitic fraction increases (DE PIPPO *et al.*, 1988).

Water circulation in the Gulf of Naples is strictly related to the general circulation in the Tyrrhenian Sea (HAPGOOD, 1960; DÜING, 1965; CARRADA *et al.*, 1980).

PENNETTA *et al.* (1998) recognise, during winter, a clockwise rotating circulation in the inner part of the gulf and a northward current offshore. Conversely, during summer, the inner circulation has an anticlockwise direction and the offshore current is towards the south. The contributions from inland determine a eutrophic coastal subsystem, that is conditioned by human activity. In particular, the Pozzuoli Gulf may be influenced by the contributions from the Volturno River and the Naples harbour.

Material and Methods

Surface sediment was collected by Van Veen grab at 20 stations located in the coastal shelf of the Pozzuoli Gulf, from the shoreline to 20 meters water-depth (Fig. 2). The position of stations was determined by DGPS (Differential Global Positioning System) (Tab.1). The sampling design was planned in order to have a good detail of the area in the vicinity of the industrial plant and to improve the data of the previous sampling phase. Characteristics of sediments such as colour, smell, grain size, presence of shell fragments

and of organic debris were described at the time of sampling. Samples for foraminiferal analyses were immediately stained with Rose Bengal for the sorting out of living specimens (WALTON, 1952; MURRAY & BOWSER, 2000). Granulometric parameters, heavy metals (Cr, Cu, Fe, Hg, Mn, Ni, Pb, Zn), Organic Matter and PAHs were determined for all the samples. Moreover, qualitative and quantitative analyses on benthic foraminiferal assemblages were performed. Samples for grain-size analysis were treated with a 30% H₂O₂ solution and separated by wet sieving. The >0.063 mm fraction was dried and fractionated by ASTM series sieves, while lower fraction was analysed by X-ray Sedigraph (ROMANO *et al.*, 1998). Later, they were classified according to Shepard (1954). Heavy metal analyses were performed on aliquot of whole homogenised sample and analysed by AAS (Atomic Absorption Spectrometry)

Table 1
Geographic coordinates and water-depth of sampling sites.

SAMPLE	Water-depth (m)	GEOGRAPHIC COORDINATES WGS 84	
		Latitude	Longitude
BE 2	4.6	40° 48.19 N	14° 10.21 E
BE 16	10.4	40° 48.31 N	14° 09.88 E
BE 23	9.9	40° 48.40 N	14° 09.82 E
BE 25	14.1	40° 48.34 N	14° 09.72 E
BE 31	7.6	40° 48.51 N	14° 09.81 E
BE 35	6.8	40° 48.61 N	14° 09.76 E
BE 39	14.4	40° 48.25 N	14° 09.75 E
BES 3	17.0	40° 48.45 N	14° 09.53 E
BES 6	16.6	40° 48.26 N	14° 09.68 E
BES 9	15.6	40° 48.13 N	14° 09.76 E
BES 15	7.5	40° 48.11 N	14° 10.02 E
SF 1	4.3	40° 48.06 N	14° 10.22 E
SF 2	10.5	40° 48.02 N	14° 09.95 E
SF 3	10.5	40° 48.66 N	14° 09.48 E
SF 4	4.3	40° 48.80 N	14° 09.69 E
SF 5	7.9	40° 48.85 N	14° 09.27 E
SF 6	6.5	40° 48.99 N	14° 08.96 E
SF 7	10.5	40° 48.89 N	14° 08.90 E
SF 8	25.5	40° 48.66 N	14° 08.81 E
SF 9	3.9	40° 48.98 N	14° 09.37 E

according to GIANI *et al.*, (1994). Organic matter was determined on previously dried sediments by loss on ignition at 450° C in a muffle furnace (BYERS *et al.*, 1987).

The 15 Polycyclic Aromatic Hydrocarbons (PAHs) indicated from Environmental Protection Agency (EPA) as important toxicological contaminants were determined: fluorene, acenaphthene, phenanthrene, anthracene, fluoranthene, pyrene, benz(a)anthracene, naphthalene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, dibenz(ah)anthracene, benzo(ghi)perylene, indeno(1, 2, 3-cd)pyrene. PAHs analyses were performed by a preliminary extraction and a successive purification on silica gel treatment; the determination by HPLC with spectrofluorimetric detector was carried out (AUSILI *et al.*, 1998).

Samples for foraminiferal analyses were washed through a 0,125 mm sieve and finally split into sub samples containing at least 300 specimens. Due to the scarce presence of living specimens, the quantitative analysis was performed only on the total assemblage. The faunal abundance was calculated through the Benthic Number (i.e. the number of tests found in 1 g of dry sediment) and the species diversity was calculated by means of the α -index (FISHER *et al.*, 1943). The LOEBLICH & TAPPAN (1988) classification was used and most of the species were compared with those found by SGARRELLA & MONCHARMONT-ZEI (1993) in their important paper on benthic foraminifers from the Gulf of Naples.

A Principal Component Analysis was performed on the results of chemical physical and foraminiferal analyses to evaluate the comprehensive behaviour of single foraminiferal species and chemical-physical parameters. Moreover, a bivariate analysis was carried out to correlate relative abundance of the single species with any chemical-physical parameter, using the Pearson correlation. The statistical treatment was performed by means of the SPSS statistical software (10.1 version). In order to simplify the matrix, only species more

abundant than 4% were considered for the statistical analyses.

Results

Chemical-physical analyses

Following Shepard (1954), all the analysed samples are constituted of sand (Tab. 2). They contain a low pelitic (<0.063 mm) fraction, which is slightly higher in front of the steel plant (up to 21%). In this area, a considerable content in vitreous drosses and iron grains is recovered in the sea-bottom. In the northern sector, coarser sediment with relatively high gravel content is present.

The organic matter in the sediments shows higher percentages in the area located between the two piers (7 - 10%) while, in the other samples, values are lower than 5% (Tab. 3). In the northern area, coarse sediments show the lowest content of organic matter (1-3%).

The highest concentrations of PAHs are recorded mainly in samples located in front of

Table 2
Particle size composition of sediments.
According to Shepard (1954).
All sediments are sand.

SAMPLE	GRAVEL %	SAND %	SILT %	CLAY %
BE 2	0,1	98,3	1,6	0,0
BE 16	0,0	86,7	11,8	1,5
BE 23	0,0	83,6	15,3	1,1
BE 25	0,0	78,9	19,2	1,9
BE 31	0,0	79,9	16,7	3,4
BE 35	0,0	95,8	4,2	0,0
BE 39	0,6	80,0	17,1	2,3
BES 3	2,0	91,9	6,1	0,0
BES 6	17,8	74,6	7,6	0,0
BES 9	1,3	85,9	11,1	1,7
BES 15	0,2	96,0	3,8	0,0
SF 1	0,8	95,0	4,2	0,0
SF 2	0,8	79,8	16,3	3,1
SF 3	0,8	97,4	1,8	0,0
SF 4	0,0	88,9	9,9	1,2
SF 5	9,2	90,7	0,1	0,0
SF 6	1,0	98,9	0,1	0,0
SF 7	4,3	95,7	0,0	0,0
SF 8	38,0	61,5	0,5	0,0
SF 9	0,1	97,3	2,6	0,0

Table 3
Concentrations of Organic Matter, PAHs and trace metals in the sediment.

SAMPLE	Organic Matter % d.w.	PAHs mg/Kg d.w.	Cr mg/Kg d.w.	Cu mg/Kg d.w.	Fe % d.w.	Hg mg/Kg d.w.	Mn mg/Kg d.w.	Ni mg/Kg d.w.	Pb mg/Kg d.w.	Zn mg/Kg d.w.
BE 2	4,4	0,134	19,7	11,6	3,1	0,09	491	6,39	99	111
BE 16	7,1	1,475	28,5	45,8	7,6	0,41	1670	13,00	254	886
BE 23	9,1	1,279	28,3	34,4	7,5	0,48	1800	12,76	465	1523
BE 25	10,0	4,783	31,6	37,7	6,0	0,53	1914	12,37	387	1346
BE 31	4,2	0,335	38,5	22,6	15,4	0,15	1349	14,20	328	582
BE 35	3,2	0,836	18,9	9,4	3,8	0,08	698	7,70	86	192
BE 39	8,8	2,252	32,6	44,7	6,0	0,75	1808	11,90	326	996
BES 3	8,0	1,589	23,7	11,0	4,3	0,12	1128	8,39	124	275
BES 6	9,2	4,716	39,6	41,5	4,7	0,44	2899	9,69	344	897
BES 9	6,8	1,225	36,5	41,0	5,8	0,39	1882	10,24	255	792
BES 15	5,4	0,283	17,5	27,0	3,7	0,23	847	7,18	171	425
SF 1	5,1	0,161	19,8	36,8	2,9	0,16	522	6,66	92	179
SF 2	5,1	2,019	26,2	48,3	4,2	0,49	950	9,50	245	578
SF 3	2,7	0,281	26,9	8,4	3,5	0,25	813	8,63	58	153
SF 4	5,9	2,651	20,3	11,6	3,3	0,14	1291	7,49	130	280
SF 5	2,6	0,084	18,3	4,1	1,7	0,01	486	7,47	16	52
SF 6	1,0	0,050	25,5	8,9	4,0	0,03	1195	9,21	34	111
SF 7	2,1	0,013	15,2	5,4	1,2	0,15	563	5,86	45	100
SF 8	3,3	0,051	5,3	8,6	2,2	0,05	1570	5,10	128	229
SF 9	9,0	0,361	24,5	8,9	3,5	0,08	1258	7,57	62	188

the industrial plant (1.2 - 4.7 mg/kg d.w.), while in the other areas they generally have low contents. Nevertheless, some samples with high PAHs concentrations (2.02 and 2.65 mg/kg d.w. for SF2 and SF4, respectively), probably due to single accidental episodes, are present at the north and south of the plant (Tab. 3).

Heavy metal analyses show generally low values for Cr, Cu and Ni. High values of Mn may be attributed to the upwelling of hydrothermal waters (CELICO *et al.*, 2001). Very high values for Fe, Pb and Zn content are recorded in front of the industrial plant. In this area, iron reaches values up to 15.4%, while in the northern and southern sector it has low values (1.2 - 4%). Similar distribution is found for Pb and Zn (Tab. 3).

Foraminiferal analyses

Relative abundance of species occurring more than 1% in at least one sample are reported in Appendix 1.

In the northern area, near to Bagnoli town (Fig. 2), all relatively coarse sediments are barren like SF5 and SF7, or have extremely low foraminiferal abundance, like SF6 and SF8. In such samples the most abundant species is *Elphidium crispum*. Many living specimens of *Haynesina germanica*, *Nonionella atlantica*, *Quinqueloculina stelligera*, *Lobatula lobatula*, *Planorbulina mediterraneensis*, *Rosalina floridana* and *Tretomphalus concinnus* were found. The last four species, which may live attached on vegetated or hard substrates, in these samples, were found living on gravel and coarse sand grains. Two samples (SF4, SF9), collected near the coast at about 4 m water depth, are characterised by relatively fine sediment and show very low foraminiferal abundance. Their assemblage is characterised by *Elphidium advena* and *Quinqueloculina dimidiata*.

Samples collected in the vicinity of the industrial plant (SF3, BE35, BE31) and near the Coroglio beach (BE2, SF1) are barren.

and *Quinqueloculina parvula* with Hg, Mn, Ni, Pb and Zn. Cu and Fe are the only ones, among the analysed metals, that have no statistically significant correlation with any foraminiferal species.

A group of variables with very low values for component 1, but high values for component 2 comprise gravel and many species that normally are abundant in coarse sediments, many of which may live attached to the grains. The positive significant correlation in the bivariate analysis between gravel and species like *Asterigerinata mamilla*, *Elphidium crispum* and *Lobatula lobatula* confirms these results. Sand is the sole variable with high negative values both for component 1 and 2. It has also significant negative correlation with some foraminiferal species (*Asterigerinata mamilla*, *Bulimina sublimbata*, *Elphidium crispum*, *E. macellum*, *Rosalina bradyi*) and with some trace metals (Mn, Ni, Pb and Zn).

Finally, PAHs show in the PCA high values for component 1 and mean values for component 2, like some species like *Bulimina sublimbata*, *Elphidium macellum*, *Miliolinella dilatata*. The similar statistical behaviour of such variables is confirmed by the significant positive correlation between these species and PAHs in the bivariate analysis.

Discussion

Benthic foraminifers have been studied with two main aims: the first one was to describe the ecological health of the sea-bottom and the second one was to try to single out bio-indicators of specific pollutants.

As regards the first aspect, foraminiferal abundance may be influenced by several natural and anthropogenic factors and, in the second case, may be indicative of environmental ecological health (ALVE, 1991; SAMIR, 2000). Two barren samples are located in the northern sector of the study area (SF5, SF7); some barren samples are located near the plant (BE31, BE35, SF3); two barren samples are

located to the south of the plant, along the Coroglio beach (BE2, SF1).

The statistical analysis (both PCA and bivariate analysis) provides evidence that foraminiferal abundance, represented by the Benthic Number, is positively linked to pelitic fraction (silt + clay). All the barren samples, except BE31, are characterised by low or very low pelitic content (0-4%). On the contrary, BE31 contains an abundant pelitic fraction (20%), but it records a general high trace metals contamination, with the highest Fe concentration (15.4%). Consequently, although in some cases the absence of foraminifers may be at least in part attributed to natural factors like the type of substrate, metal pollution also seems to contribute to such phenomenon.

As regards the second goal of this research, PCA evidences two groups of species with distinct statistical behaviour (Fig. 4). The largest group (*Quinqueloculina dimidiata*, *Q. laevigata*, *Q. stelligera*, *Miliolinella subrotunda*, *Haynesina germanica*, *Elphidium advena* among the others) prefers to live in bottoms with relatively high pelitic fraction and organic matter content. Such type of sediment is favourable for the accumulation of some trace metals like Hg, Mn, Ni, Pb and Zn, owing to the absorptive properties of clay minerals. The concurrence of certain species and some metals may be due to their preference for the same type of sediments. Nevertheless, the positive correlation between many species and some trace metals, revealed by the bivariate analysis, let us suppose a certain tolerance of metal pollution. *Haynesina germanica*, *Miliolinella subrotunda* and *Quinqueloculina parvula* seem the most tolerant species because they are positively correlated with many metals (Hg, Mn, Ni, Pb and Zn). DEBENAY *et al.*, (2001) consider *Haynesina germanica* a tolerant and pioneer species because it was found in the metal polluted sediments of the Port Joinville Harbour and shows a significant positive correlation with Pb in the bivariate analysis. A significant Pearson correlation was also found

between *Bulimina sublimbata*, *Elphidium macellum*, *Miliolinella dilatata* and PAHs.

The group of species with high component 2 values in the PCA (*Neoconorbina terquemi*, *Asterigerinata mamilla*, *Lobatula lobatula*, *Elphidium crispum*, among others) is not influenced by the organic matter content, while it is strictly linked to coarse sediment. Among these species no one shows a significant correlation with any type of metal pollution.

Conclusions

The strongest heavy metal pollution, mainly due to Fe, Pb and Zn, is recorded in the sediments close to the plant, while it rapidly diminishes with increasing distance from it. Such pollutants seem to have strong environmental impact on the sea-bottom's ecological health because they might be, at least in part, responsible for the complete absence of foraminifers. In a previous study on the Bagnoli site, Bergamin *et al.* (in press) deduced that the absence of foraminifers near the plant, especially between the two piers, could be attributed mainly to iron and copper contamination.

Appendix 1

Relative abundance of foraminifers, Alpha-index and Benthic Number. Species occurring more than 1% in at least one sample are reported.

	BE16	BE23	BE25	BE39	BES3	BES6	BES9	BES15	SF2	SF4	SF6	SF8	SF9
<i>Adelosina carinata striata</i>	0.00	0.46	0.00	0.94	0.47	0.00	1.41	0.00	1.64	0.49	0.00	0.00	1.50
<i>Adelosina cliariensis</i>	2.33	2.78	0.99	0.47	1.41	1.39	2.82	2.84	2.46	0.98	1.66	0.45	0.00
<i>Ammonia inflata</i>	0.00	0.00	0.00	0.00	0.00	0.46	0.00	0.00	0.41	0.00	1.10	2.26	0.00
<i>Ammonia parkinsoniana</i>	0.93	1.39	0.49	1.41	2.36	0.00	0.94	1.42	1.64	2.95	3.31	0.90	2.00
<i>Ammonia tepida</i>	0.93	0.00	1.97	1.41	0.00	0.00	0.47	0.47	2.46	0.00	0.00	0.00	0.00

Some trace metals, Hg, Mn, Ni, Pb and Zn, are positively linked to pelite rich sediments, like a large proportion of foraminiferal species. Their concurrence in the same bottom-environment evidences that, at the recorded concentrations, many foraminiferal species have a good tolerance of these metals. *Haynesina germanica*, *Miliolinella subrotunda* and *Quinqueloculina parvula* are particularly tolerant of a trace metal polluted environment. On the contrary, no foraminiferal species demonstrated to tolerate copper and iron-polluted environment. In addition, a good tolerance of PAHs pollution may be supposed for *Bulimina sublimbata*, *Elphidium macellum* and *Miliolinella dilatata*.

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Appendix 1 (Continued)

	BE16	BE23	BE25	BE39	BES3	BES6	BES9	BES15	SF2	SF4	SF6	SF8	SF9
<i>Asterigerinata mamilla</i>	0.93	0.46	0.49	3.77	2.36	6.97	1.41	0.47	0.00	1.48	0.55	4.98	3.00
<i>Asterigerinata mariae</i>	0.46	0.00	0.00	1.41	0.00	0.46	0.94	0.00	0.00	0.00	0.00	0.00	0.00
<i>Astrononion stelligerum</i>	0.46	0.00	0.00	0.94	0.00	0.93	1.41	0.00	0.00	1.48	0.00	0.90	0.50
<i>Buccella granulata</i>	4.19	7.90	2.47	2.36	6.13	2.33	2.35	4.26	1.64	2.46	1.10	0.00	4.00
<i>Bulimina aculeata</i>	0.46	0.00	0.49	0.00	0.47	2.33	5.16	2.37	1.64	0.00	0.00	0.00	0.00
<i>Bulimina cf. exilis</i>	0.00	0.00	0.00	7.54	0.94	0.93	0.00	0.00	0.00	0.98	0.00	0.00	0.00
<i>Bulimina sublimbata</i>	2.33	1.39	6.44	1.41	1.41	5.11	0.94	0.00	1.64	0.00	0.00	0.00	0.00
<i>Cibicides refulgens</i>	1.39	1.39	0.00	0.47	0.47	0.00	1.41	0.95	1.23	1.48	0.00	0.00	2.00
<i>Cornuspira involvens</i>	0.00	0.93	0.99	0.47	0.00	1.39	0.47	1.42	2.05	0.98	0.00	0.00	0.50
<i>Elphidium aculeatum</i>	0.00	0.00	0.49	0.47	0.47	0.00	0.94	0.47	0.00	0.00	0.00	2.72	2.00
<i>Elphidium advena</i>	12.56	8.84	5.45	8.02	12.26	3.25	6.10	13.74	9.84	13.79	1.10	0.00	12.00
<i>Elphidium crispum</i>	0.00	0.00	0.00	0.00	0.00	3.25	0.94	2.84	1.64	0.00	19.88	30.77	0.00
<i>Elphidium granosum</i>	0.00	0.46	1.48	0.94	0.47	0.00	0.47	0.00	2.87	0.00	0.00	0.00	0.00
<i>Elphidium jenseni</i>	0.00	0.00	0.49	0.00	0.47	0.93	0.00	0.47	0.41	1.48	0.55	3.17	3.50
<i>Elphidium macellum</i>	0.93	0.93	1.98	3.77	0.47	5.58	0.00	0.95	4.10	0.00	0.55	0.45	1.00
<i>Elphidium pulvereum</i>	3.71	0.00	0.49	0.94	2.83	0.00	3.28	0.95	2.46	1.97	0.55	0.45	1.50
<i>Elphidium sp.</i>	2.79	1.86	0.98	1.89	2.36	0.46	1.41	1.42	0.82	2.95	0.55	0.00	0.50
<i>Fursenkoina acuta</i>	0.00	0.00	0.49	0.00	1.41	0.00	0.00	0.00	0.41	0.00	0.00	0.00	0.50
<i>Gavelinopsis praegeri</i>	0.00	0.00	0.00	1.41	0.00	0.00	0.94	0.00	0.00	2.46	0.00	0.45	0.00
<i>Glabratella erecta</i>	0.00	0.00	1.48	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Hanzawayia boueana</i>	0.00	0.00	0.00	0.00	0.00	0.46	0.47	0.00	0.00	0.98	0.00	1.36	0.50
<i>Haynesina depressula</i>	0.93	1.39	1.97	1.89	0.47	0.00	1.41	0.00	4.10	0.49	9.39	0.00	3.00
<i>Haynesina germanica</i>	0.46	2.79	4.45	0.94	3.30	0.00	1.88	2.36	2.05	0.49	0.00	0.00	1.50
<i>Lenticulina cultrata</i>	1.85	0.46	0.49	0.94	0.47	0.46	1.41	0.00	0.00	0.00	0.00	0.00	0.00
<i>Lobatula lobatula</i>	2.33	0.00	1.48	5.19	4.24	13.01	9.86	4.74	7.38	5.42	3.31	22.17	9.00
<i>Miliolinella semicostata</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.73	0.00	3.00

Appendix 1 (Continued)

	BE16	BE23	BE25	BE39	BES3	BES6	BES9	BES15	SF2	SF4	SF6	SF8	SF9
<i>Miliolinella subrotunda</i>	4.17	3.71	5.44	4.72	4.72	5.11	7.05	1.89	3.69	5.90	0.00	1.35	3.50
<i>Neoconorbina posidonicola</i>	1.86	0.00	0.49	1.41	1.41	0.46	5.63	0.00	0.00	1.48	0.00	0.00	1.00
<i>Neoconorbina terquemi</i>	0.46	0.93	2.47	0.00	0.94	2.33	0.47	0.00	1.23	1.48	6.63	2.71	0.00
<i>Nonionella atlantica</i>	3.72	3.25	2.47	1.41	0.47	0.00	0.94	1.42	2.87	0.00	0.55	0.00	0.00
<i>Peneroplis pertusus</i>	0.00	0.00	0.00	0.00	0.00	0.93	0.00	0.00	0.00	0.00	2.76	0.00	2.50
<i>Planorbulina mediterraneensis</i>	0.00	0.00	0.99	0.47	0.00	0.93	1.41	0.00	0.82	0.49	0.00	3.17	0.50
<i>Pseudotriloculina subgranulata</i>	0.92	0.46	0.00	0.00	0.00	0.00	0.00	0.47	1.23	0.00	0.00	0.45	0.00
<i>Quinqueloculina annectens</i>	1.39	0.46	0.49	1.89	2.35	0.93	3.75	5.69	0.00	0.00	0.55	0.45	1.00
<i>Quinqueloculina auberiana</i>	0.46	0.00	0.00	0.00	0.47	1.39	4.23	0.00	0.41	0.98	8.28	2.71	0.50
<i>Quinqueloculina berthelotiana</i>	0.00	0.00	2.97	0.94	0.47	6.05	2.82	4.74	5.74	0.00	0.00	0.90	1.00
<i>Quinqueloculina bosciana</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00
<i>Quinqueloculina dimidiata</i>	15.36	14.88	14.85	6.59	9.90	5.12	6.11	4.73	2.05	23.88	2.75	0.00	12.00
<i>Quinqueloculina laevigata</i>	4.19	6.98	1.98	1.89	7.55	1.85	2.35	3.32	2.46	0.98	0.00	0.45	1.50
<i>Quinqueloculina parvula</i>	2.33	2.79	3.96	2.83	1.41	2.33	0.00	3.32	0.82	0.00	1.10	0.00	1.50
<i>Quinqueloculina seminulum</i>	0.93	3.25	1.98	1.89	1.89	3.25	1.88	1.89	0.82	1.48	2.76	1.35	1.00
<i>Quinqueloculina stalkerii</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.47	0.00	0.00	9.36	0.00	0.00	6.00
<i>Quinqueloculina stelligera</i>	10.70	8.37	4.95	2.36	10.38	0.00	0.00	4.26	0.82	1.97	1.10	0.00	5.50
<i>Rosalina bradyi</i>	2.79	1.86	1.98	1.89	2.36	3.25	5.16	5.21	10.25	0.00	0.55	6.79	4.00
<i>Rosalina floridana</i>	0.00	0.00	0.99	0.00	0.47	6.51	0.00	0.00	0.00	5.42	4.41	0.90	2.00
<i>Siphonaperta aspera</i>	0.93	1.39	0.00	0.47	0.47	0.00	0.00	3.79	1.64	0.48	11.04	0.90	0.00
<i>Tretomphalus concinnus</i>	1.39	1.39	0.49	3.30	1.89	0.00	0.47	0.00	0.82	3.44	0.55	0.00	1.00
<i>Triloculina plicata</i>	4.65	13.95	10.39	9.90	3.77	4.19	6.10	12.80	9.43	0.49	0.55	0.90	0.00
<i>Triloculina tricarinata</i>	0.00	0.00	0.00	1.41	0.47	0.00	0.47	0.00	0.00	0.00	0.00	0.00	0.00
<i>Vertebralina striata</i>	0.93	0.46	0.49	1.89	0.94	0.00	0.47	0.95	0.41	1.48	0.00	0.00	0.50
Alpha-index	40.0	26.1	19.2	38.1	38.3	34.4	30.1	22.4	32.4	26.4	18.2	20.3	29.8
Benthic Number	128.6	150.7	188.3	217.4	28.0	257.8	181.6	139.8	2159.5	33.9	1.8	3.8	7.1

Appendix 2

Correlation between relative abundance of selected species of foraminifers ($>5\%$ in at least 1 sample) and the chemical-physical parameters of sediments. Only variables with significant Pearson Correlation are reported.

	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Zn	PAHs	OM	gravel	sand	silt	clay	silt+clay
<i>Asterigerinata mamilla</i>	Pearson Correlation Sig. (2-tailed) N	0,151 -0,098 26	-0,242 0,234 26	0 0,998 26	0,244 0,229 26	0,004 0,984 26	0,197 0,335 26	0,077 0,708 26	0,451 0,021 26	0,440 0,024 26	0,661 0,000 26	-0,566 0,003 26	0,006 0,976 26	-0,116 0,571 26	-0,012 0,955 26
<i>Buccella granulata</i>	Pearson Correlation Sig. (2-tailed) N	0,205 0,314 26	-0,114 0,58 26	0,242 0,233 26	0,098 0,634 26	0,254 0,211 26	0,424 0,031 26	0,298 0,139 26	0,213 0,297 26	0,518 0,007 26	-0,196 0,336 26	0,002 0,992 26	0,249 0,221 26	0,006 0,975 26	0,217 0,287 26
<i>Bulimina aculeata</i>	Pearson Correlation Sig. (2-tailed) N	-0,002 0,990 26	0,047 0,82 26	0,38 0,055 26	0,801 0 26	0,531 0,005 26	0,344 0,085 26	0,674 0,000 26	0,194 0,342 26	0,218 0,284 26	-0,031 0,881 26	-0,224 0,271 26	0,328 0,102 26	0,258 0,202 26	0,323 0,108 26
<i>Bulimina sublimbata</i>	Pearson Correlation Sig. (2-tailed) N	0,493 0,010 26	0,021 0,918 26	-0,123 0,551 26	0,271 0,180 26	0,305 0,13 26	0,585 0,002 26	0,463 0,017 26	0,895 0 26	0,668 0,000 26	0,108 0,598 26	-0,477 0,014 26	0,520 0,006 26	0,279 0,168 26	0,493 0,011 26
<i>Elphidium crispum</i>	Pearson Correlation Sig. (2-tailed) N	-0,387 0,051 26	-0,118 0,564 26	-0,205 0,315 26	0,029 0,138 26	-0,14 0,483 26	-0,196 0,336 26	-0,163 0,425 26	-0,17 0,415 26	-0,308 0,125 26	0,755 0,000 26	-0,431 0,028 26	-0,301 0,135 26	-0,197 0,335 26	-0,290 0,151 26
<i>Elphidium macellum</i>	Pearson Correlation Sig. (2-tailed) N	0,408 0,039 26	0,018 0,93 26	-0,18 0,38 26	0,332 0,097 26	0,259 0,201 26	0,503 0,009 26	0,371 0,062 26	0,710 0 26	0,530 0,005 26	0,197 0,335 26	-0,504 0,009 26	0,437 0,025 26	0,324 0,106 26	0,427 0,030 26
<i>Haynesina germanica</i>	Pearson Correlation Sig. (2-tailed) N	-0,024 0,909 26	-0,052 0,801 26	0,008 0,971 26	0,498 0,032 26	0,502 0,009 26	0,455 0,020 26	0,649 0,000 26	0,379 0,056 26	0,502 0,009 26	-0,234 0,250 26	-0,172 0,402 26	0,514 0,007 26	0,238 0,241 26	0,482 0,013 26
<i>Lobatula lobatula</i>	Pearson Correlation Sig. (2-tailed) N	-0,112 0,587 26	-0,122 0,551 26	-0,272 0,18 26	0,208 0,309 26	-0,05 0,808 26	0,051 0,805 26	0,014 0,947 26	0,23 0,259 26	0,215 0,292 26	0,781 0,000 26	-0,659 0,000 26	-0,026 0,898 26	-0,022 0,917 26	-0,026 0,900 26
<i>Miliolinella dilatata</i>	Pearson Correlation Sig. (2-tailed) N	0,371 0,062 26	-0,084 0,683 26	-0,209 0,305 26	0,193 0,344 26	0,271 0,18 26	0,456 0,019 26	0,385 0,052 26	0,723 0 26	0,845 0,000 26	-0,030 0,883 26	-0,347 0,083 26	0,511 0,008 26	0,248 0,222 26	0,480 0,013 26
<i>Miliolinella subrotunda</i>	Pearson Correlation Sig. (2-tailed) N	-0,021 0,919 26	-0,018 0,931 26	0,049 0,811 26	0,813 0,000 26	0,589 0,002 26	0,390 0,049 26	0,688 0,000 26	0,297 0,141 26	0,286 0,156 26	-0,057 0,781 26	-0,285 0,158 26	0,445 0,023 26	0,298 0,139 26	0,431 0,028 26

<i>Quinqueloculina berthelotiana</i>	Pearson Correlation Sig. (2-tailed) N	0,297 0,141 26	0,006 0,975 26	-0,22 0,281 26	0,120 0,560 26	0,136 0,506 26	0,08 0,698 26	0,338 0,091 26	0,202 0,323 26	0,576 0,002 26	0,398 0,044 26	0,203 0,320 26	-0,398 0,044 26	0,288 0,153 26	0,235 0,248 26	0,285 0,159 26
<i>Quinqueloculina dimidiata</i>	Pearson Correlation Sig. (2-tailed) N	0,133 0,516 26	-0,11 0,594 26	-0,087 0,674 26	0,244 0,230 26	0,382 0,054 26	0,420 0,033 26	0,380 0,056 26	0,479 0,013 26	0,489 0,11 26	0,597 0,001 26	-0,233 0,253 26	-0,142 0,488 26	0,473 0,015 26	0,218 0,285 26	0,443 0,023 26
<i>Quinqueloculina laevigata</i>	Pearson Correlation Sig. (2-tailed) N	0,210 0,302 26	-0,073 0,724 26	-0,17 0,406 26	0,097 0,637 26	0,056 0,785 26	0,241 0,235 26	0,437 0,026 26	0,315 0,118 26	0,313 0,119 26	0,600 0,001 26	-0,097 0,636 26	-0,163 0,425 26	0,347 0,083 26	0,124 0,545 26	0,319 0,112 26
<i>Quinqueloculina parvula</i>	Pearson Correlation Sig. (2-tailed) N	0,051 0,805 26	-0,006 0,975 26	-0,072 0,726 26	0,506 0,008 26	0,734 0,000 26	0,653 0 26	0,616 0,001 26	0,831 0,000 26	0,444 0,023 26	0,546 0,004 26	-0,130 0,528 26	-0,250 0,217 26	0,497 0,010 26	0,244 0,230 26	0,467 0,016 26
<i>Quinqueloculina stelligera</i>	Pearson Correlation Sig. (2-tailed) N	0,135 0,512 26	-0,117 0,568 26	0,038 0,852 26	0,176 0,391 26	0,010 0,963 26	0,216 0,290 26	0,188 0,357 26	0,174 0,394 26	0,113 0,584 26	0,418 0,033 26	-0,229 0,260 26	0,054 0,794 26	0,220 0,281 26	-0,033 0,873 26	0,187 0,361 26
<i>Rosalina floridana</i>	Pearson Correlation Sig. (2-tailed) N	0,187 0,359 26	-0,104 0,613 26	-0,220 0,280 26	-0,204 0,317 26	0,173 0,399 26	-0,010 0,962 26	-0,018 0,930 26	-0,039 0,849 26	0,500 0,009 26	0,179 0,382 26	0,258 0,203 26	-0,168 0,413 26	-0,060 0,770 26	-0,143 0,485 26	-0,073 0,722 26
<i>Tretomphalus concinnus</i>	Pearson Correlation Sig. (2-tailed) N	-0,187 0,361 26	-0,003 0,989 26	0,014 0,946 26	0,459 0,018 26	0,812 0,000 26	0,612 0,001 26	0,331 0,098 26	0,702 0,000 26	0,165 0,422 26	0,235 0,248 26	-0,168 0,413 26	-0,151 0,461 26	0,392 0,048 26	0,284 0,160 26	0,382 0,054 26
<i>Triloculina plicata</i>	Pearson Correlation Sig. (2-tailed) N	0,245 0,227 26	0,006 0,976 26	-0,166 0,417 26	0,345 0,084 26	0,234 0,251 26	0,393 0,047 26	0,678 0,000 26	0,597 0,001 26	0,485 0,012 26	0,610 0,001 26	-0,114 0,580 26	-0,367 0,065 26	0,618 0,001 26	0,425 0,030 26	0,599 0,001 26
Benthic Number	Pearson Correlation Sig. (2-tailed) N	-0,105 0,609 26	0,062 0,764 26	-0,004 0,983 26	0,431 0,028 26	0,629 0,001 26	0,500 0,009 26	0,334 0,096 26	0,601 0,001 26	0,215 0,292 26	0,125 0,544 26	-0,087 0,674 26	-0,294 0,144 26	0,466 0,016 26	0,483 0,012 26	0,475 0,014 26
Alpha-index	Pearson Correlation Sig. (2-tailed) N	0,191 0,349 26	-0,093 0,65 26	-0,230 0,259 26	0,287 0,155 26	0,534 0,005 26	0,492 0,011 26	0,453 0,020 26	0,553 0,003 26	0,528 0,006 26	0,663 0,000 26	0,085 0,679 26	-0,447 0,022 26	0,498 0,010 26	0,322 0,108 26	0,479 0,013 26
Cr	Pearson Correlation Sig. (2-tailed) N	1 26	-0,046 0,823 26	0,372 0,062 26	0,202 0,323 26	0,085 0,680 26	0,351 0,078 26	0,494 0,010 26	0,224 0,270 26	0,484 0,012 26	0,443 0,024 26	-0,342 0,087 26	-0,124 0,547 26	0,542 0,004 26	0,484 0,012 26	0,542 0,004 26
Cu	Pearson Correlation Sig. (2-tailed) N	-0,046 0,823 26	1 26	0,046 0,825 26	0,540 0,004 26	-0,008 0,968 26	-0,309 0,125 26	0,188 0,358 26	0,054 0,792 26	-0,01 0,979 26	-0,038 0,853 26	-0,103 0,618 26	0,121 0,557 26	-0,047 0,818 26	0,005 0,979 26	-0,041 0,844 26

Appendix 2 (Continued)

Hg	Pearson Correlation Sig. (2-tailed) N	0,202 0,323 26	0,540 0,004 26	0,258 0,202 26	1	0,477 0,014 26	0,194 0,343 26	0,628 0,001 26	0,586 0,002 26	0,25 0,218 26	0,289 0,153 26	-0,247 0,223 26	-0,092 0,656 26	0,408 0,039 26	0,272 0,179 26	0,394 0,046 26
Mn	Pearson Correlation Sig. (2-tailed) N	0,085 0,680 26	-0,008 0,968 26	0,180 0,378 26	0,477 0,014 26	1 0,000 26	0,698 0,000 26	0,543 0,004 26	0,860 0,000 26	0,386 0,051 26	0,392 0,047 26	0,086 0,677 26	-0,444 0,023 26	0,493 0,011 26	0,319 0,113 26	0,475 0,014 26
Ni	Pearson Correlation Sig. (2-tailed) N	0,351 0,078 26	-0,309 0,125 26	0,108 0,600 26	0,194 0,343 26	0,698 0,000 26	1 0,004 26	0,542 0,004 26	0,776 0,000 26	0,371 0,062 26	0,355 0,075 26	-0,186 0,362 26	-0,404 0,041 26	0,733 0,000 26	0,625 0,001 26	0,728 0,000 26
Pb	Pearson Correlation Sig. (2-tailed) N	0,494 0,010 26	0,188 0,358 26	0,186 0,364 26	0,628 0,001 26	0,543 0,004 26	0,542 0,004 26	1 0,000 26	0,811 0,000 26	0,580 0,002 26	0,640 0,000 26	-0,077 0,708 26	-0,536 0,005 26	0,789 0,000 26	0,614 0,001 26	0,775 0,000 26
Zn	Pearson Correlation Sig. (2-tailed) N	0,224 0,270 26	0,054 0,792 26	0,116 0,572 26	0,586 0,002 26	0,86 0,000 26	0,776 0,000 26	0,811 0,000 26	1 0,000 26	0,505 0,008 26	0,583 0,002 26	-0,108 0,601 26	-0,473 0,015 26	0,751 0,000 26	0,526 0,006 26	0,729 0,000 26
PAHs	Pearson Correlation Sig. (2-tailed) N	0,484 0,012 26	-0,005 0,979 26	-0,084 0,685 26	0,250 0,218 26	0,386 0,051 26	0,371 0,062 26	0,580 0,002 26	0,505 0,008 26	1 0,000 26	0,702 0,000 26	0,052 0,799 26	-0,513 0,007 26	0,626 0,001 26	0,388 0,050 26	0,600 0,001 26
OM	Pearson Correlation Sig. (2-tailed) N	0,443 0,024 26	-0,038 0,854 26	-0,038 0,853 26	0,289 0,153 26	0,392 0,047 26	0,355 0,075 26	0,640 0,000 26	0,583 0,002 26	0,702 0,000 26	1 0,000 26	-0,094 0,649 26	-0,373 0,061 26	0,619 0,001 26	0,317 0,115 26	0,584 0,002 26
sand	Pearson Correlation Sig. (2-tailed) N	-0,124 0,547 26	0,121 0,557 26	0,025 0,903 26	-0,092 0,656 26	-0,444 0,023 26	-0,404 0,041 26	-0,536 0,005 26	-0,473 0,015 26	-0,513 0,007 26	-0,373 0,061 26	-0,662 0,000 26	1 0,000 26	-0,543 0,004 26	-0,506 0,008 26	-0,545 0,004 26
silt	Pearson Correlation Sig. (2-tailed) N	0,542 0,004 26	-0,047 0,818 26	0,237 0,245 26	0,408 0,039 26	0,493 0,011 26	0,733 0,000 26	0,789 0,000 26	0,751 0,000 26	0,626 0,001 26	0,619 0,001 26	-0,268 0,186 26	-0,543 0,004 26	1 0,000 26	0,885 0,000 26	0,998 0,000 26
clay	Pearson Correlation Sig. (2-tailed) N	0,484 0,012 26	0,005 0,979 26	0,230 0,258 26	0,272 0,179 26	0,319 0,113 26	0,625 0,001 26	0,614 0,001 26	0,526 0,006 26	0,388 0,050 26	0,317 0,115 26	-0,236 0,246 26	-0,506 0,008 26	0,885 0,000 26	1 0,000 26	0,914 0,000 26
silt+clay	Pearson Correlation Sig. (2-tailed) N	0,542 0,004 26	-0,041 0,844 26	0,240 0,239 26	0,394 0,046 26	0,475 0,014 26	0,728 0,000 26	0,775 0,000 26	0,729 0,000 26	0,600 0,001 26	0,584 0,002 26	-0,267 0,187 26	-0,545 0,004 26	0,998 0,000 26	0,914 0,000 26	1 0,000 26

LEGEND **Bold** Correlation is significant at the 0,05 level (2-tailed)

Bold Underlined Correlation is significant at the 0,001 level (2-tailed)

References

- ALVE, E., 1991. Benthic Foraminifera in sediment cores reflecting heavy metal pollution in Sørffjord, Western Norway. *Journal Foraminiferal Research*, 21 (1): 1-19.
- ALVE, E. and OLSGARD, F., 1999. Benthic foraminiferal colonization in experiments with copper-contaminated sediments. *Journal Foraminiferal Research*, 29 (3): 186-195.
- AUSILI, A., PELLEGRINI, D., ONORATI, F. & DE RANIERI, S., 1998. Valutazione delle qualità di sedimenti del Porto di Viareggio da sottoporre ad escavo. *Acqua Aria*, January: 67-71.
- BERGAMIN, L., ROMANO, E., CELIA MAGNO, M., AUSILI, A. & GABELLINI, M. Pollution monitoring of Bagnoli Bay (Tyrrhenian Sea, Naples, Italy): a chemical-physical and ecological approach. *Aquatic Ecosystem, Health & Management*, in press.
- BYERS, S. C., MILLS, L. E. & STEWART, P. L., 1987. A comparison of methods of determining organic in marine sediments, with suggestions for a standard method. *Hydrobiologia*, 58: 43-47.
- CARRADA, G.C., HOPKINS, T.S., BONADUCE, G., IANORA, A., MARINO, D., MODIGH, M., RIBERA D'ALCALÀ, M. & SCOTTO DI CARLO, B., 1980. Variability in the hydrographic and biological features of the Gulf of Naples. *Marine Ecology*, 1: 105-120.
- CELICO, F., ESPOSITO, L. & MANCUSO, M., 2001. Complessità idrodinamica e idrochimica dell'area urbana di Napoli: scenari interpretativi. *Geologia tecnica e ambientale*, 2: 35-54.
- COCCIONI, R., 2000. Benthic foraminifera as bioindicators of heavy metal pollution. A case study from the Goro Lagoon (Italy). Vol 15, p. 71-103. *In: Topics in Geobiology*, edited by R.E. Martin, New York, Kluwer Academic/Plenum Publishers.
- DE PIPPO, T., DI CARA, A., GUIDA, M., PESCATORE, T. & RENDA, P., 1984. Contributi allo studio del Golfo di Pozzuoli: lineamenti di geomorfologia. *Memorie Società Geologica Italiana*, 27:151-159.
- DE PIPPO, T., PESCATORE, T. & VECCHIONE, C., 1988. Caratteri granulometrici dei sedimenti dei terrazzi del Golfo di Pozzuoli. *Memorie Società Geologica Italiana*, 41: 1005-1014.
- DEBENAY, J.P., TSAKIRIDIS, E., SOULARD, R. & GROSSEL, H., 2001. Factors determining the distribution of foraminiferal assemblages in Port Joinville Harbor (Ile d'Yeu, France): the influence of pollution. *Marine Micropaleontology*, 43: 75-118.
- DÜING, W., 1965. Strömungsverhältnisse im Golf von Neapel. *Pubblicazioni Stazione Zoologica Napoli*, 34: 256-316.
- GIANI, M., GABELLINI, M., PELLEGRINI, D., COSTANTINI, S., BECCALONI, E. & GIORDANO, R., 1994. Concentration and partitioning of Cr, Hg and Pb in sediments of dredge and disposal sites of the northern Adriatic sea. *Science of Total Environment*, 158: 97-112.
- FISHER R.A., CORBET A.S. & WILLIAMS, C.B. (1943). The relation between the number of species and the number of individuals in a random sample of an animal population. *Journal of Animal Ecology*, 12: 42-58.
- HAPGOOD, H.W., 1960. Hydrographic observations in the Bay of Naples (Gulf of Naples). January 1957 - January 1958 (Stations list). *Pubblicazioni Stazione Zoologica di Napoli*, 31: 337-371.
- LOEBLICH, A. R. & TAPPAN, H., 1988. Foraminiferal Genera and their Classification. New York, Van Nostrand Reinhold Comp., 970 p.
- MURRAY, J. W. & BOWSER, S. S., 2000. Mortality, protoplasm decay rate, and reliability of staining techniques to recognize 'living' foraminifera: a review. *Journal of Foraminiferal Research*, 30 (1): 66-70.
- PENNETTA, M., VALENTE, A., ABATE, D., BOUDILLON, G., DE PIPPO, T., LEONE, M. & TERLIZZI, F., 1998. Influenza della morfologia costiera sulla circolazione e sedimentazione sulla piattaforma continentale campano-laziale tra Gaeta e Cuma (Italia meridionale). *Bollettino Società Geologica Italiana*, 117: 281-295.
- ROMANO, E., GABELLINI, M., PELLEGRINI, D., AUSILI, A. & MELLARA, F., 1998. Metalli in tracce e contaminanti organici provenienti da differenti aree marine costiere in relazione alla movimentazione dei fondali. *Proceedings 12° A.I.O.L Conference*, Vol. II: 473-486.
- SAMIR, A. M., 2000. The response of benthic foraminifera and ostracods to various pollution sources: a study from two lagoons in Egypt. *Journal Foraminiferal Research*, 30:83-98.
- SAMIR, A. M. & EL-DIN, A. B., 2001. Benthic foraminiferal assemblages and morphological

- abnormalities as pollution proxies in two Egyptian bays. *Marine Micropaleontology*, 41: 193-227.
- SGARRELLA, F. & MONCHARMONT-ZEI, M., 1993. Benthic Foraminifera of the Gulf of Naples (Italy): systematics and autoecology. *Bollettino Società Paleontologica Italiana*, 32 (2): 145-264.
- SHEPARD, F. P., 1954. Nomenclature based on sand-silt-clay ratios. *Journal Sedimentary Petrology*, 24: 151-158.
- STOUFF, V., DEBENAY, J. P. & LESOURD M., 1999. Origin of double and multiple tests in benthic foraminifera: observations in laboratory cultures. *Marine Micropaleontology*, 12: 189-204.
- WALTON, W. R., 1952. Techniques for recognition of living foraminifera. *Contributions Cushman Foundation for Foraminiferal Research*, 3: 56-60.
- YANKO, V., KRONFELD, J. & FLEXER, A., 1994. Response of benthic foraminifera to various pollution sources: implication for pollution monitoring. *Journal of Foraminiferal Research*, 24 (1): 1-17.
- YANKO, V., AHMAD, M. & KAMINSKY, M., 1998. Morphological deformities of benthic foraminiferal tests in response to pollution by heavy metals: implications for pollution monitoring. *Journal of Foraminiferal Research*, 28 (3): 177-200.